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## **Simulations in the development process of low-voltage circuit-breakers**

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### **ABSTRACT**

Low-voltage circuit breakers are important devices in today's electrical distribution system, especially in industrial applications. Their main features are the fast and reliable protection against any currents that exceed operational levels and the ability to conduct rated current continuously without the Joule heat losses leading to excessive temperature rise.

The development process is characterized by the demand for a short time-to-market requiring that the first design is able to fulfil the main specifications. In this contribution we describe the use of simulation tools for the calculation of the short-circuit behaviour of current limiting breakers as well as the temperature distribution under rated-current conditions. A comparison of the simulations to experiments conducted on a prototype model of the breaker shows good agreement.

### **INTRODUCTION**

Circuit breakers are widely used as protective devices in low-voltage applications. Protection against short circuit currents is the most crucial protective property of any circuit breaker. Current limiting breakers are characterized by a rapid extinction of the short-circuit current well before the next current zero of operational frequency is reached. This enables the operation of electrical systems with very high short-circuit currents in much smaller volumes than with traditional current-zero quenching breakers combined with an effective protection of the electrical installation.

Experimental investigations of the short-circuit breaking capacity are very expensive and they can only be performed late in the development process since a realistic prototype with all the relevant components is needed. The increased computing performance and the quality of available software facilitates the simulation of the behaviour of a circuit breaker under short circuit conditions as shown in some publications, e.g. [1],[2],[3].

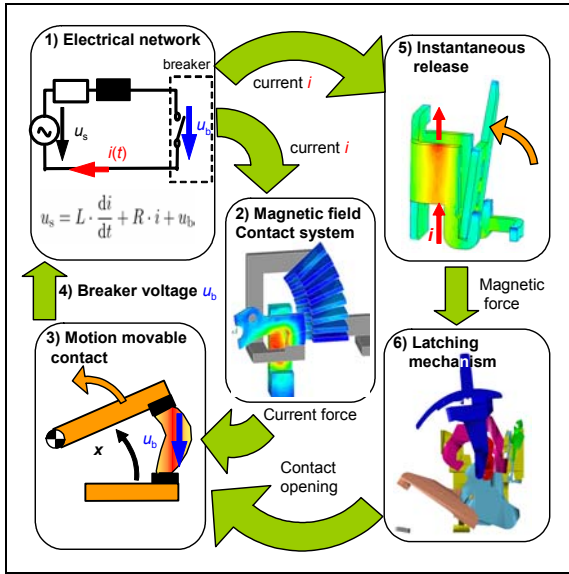
It is well known that the current in electrical switching devices causes unwanted power loss resulting in heating of the devices and their surroundings. The increasing miniaturization of the devices with unchanged rated current and subsequently rising power loss per volume leads to increasing demands for the developer. For a typical circuit breaker the power loss per volume has increased more than fourfold from  $6 \text{ W/m}^3$  to  $27 \text{ W/m}^3$  in the last fifty years [4]. Thus three-dimensional simulations of the temperature behaviour of switching devices have reached an increased importance as shown exemplary in [5]

### **SIMULATION MODELS**

#### **Short-circuit calculations**

In the simulation model we combine the solution of differential equations with finite element calculations. While the electrical network and the movable parts of the breaker are represented as concentrated elements using a system modeller [6], the magnetic forces for the movable contact and the short-circuit release are simulated with finite

elements [7]. The simulation procedure is shown in **Fig. 1** and is described as follows:



**Fig. 1** Flowchart of short-circuit calculations

1. The electrical network consists of the source voltage, the impedance of the cables, and the breaker, that interacts with the electrical network through the voltage  $u_b$  across its terminals
2. The force on the movable contacts due to the current is calculated using a finite element model. The results are provided as a matrix of force depending on circuit current and opening angle of the movable contact.
3. When the electromagnetic force on the movable contact exceeds the force of the contact springs the motion of the movable contact starts and an electrical arc is ignited between the contact pieces.
4. The arc is characterized by its arc voltage which we describe using an approach according to Pohl [1] who calculates the arc voltage as a linear function of the position  $x$  of the movable contact. The maximum arc voltage is reached when the contacts are completely opened; we calculate it from the electrode fall voltage of the serial arcs split between the splitter plates.
5. Parallel to step 2 the current also trips the instantaneous short-circuit release. In analogy to the movable contact the mag-

netic force on the armature has been calculated in advance. The armature moves when the magnetic force exceeds the counter force of the spring and it releases the latching mechanism.

6. After the latching mechanism is released the movable contacts will be opened within a few milliseconds. If the movable contacts have already opened dynamically due to high short-circuit currents the latching mechanism prevents re-closure of the contacts and subsequent reignition of the arc.

The tripping time of the latching mechanism is calculated with multi body simulations and is transferred to this short-circuit simulation model as a parameter.

In this model for current limiting breakers the current is quenched at the next current zero when the arc voltage before current zero is higher than the recovery voltage of the network that appears across the open contacts.

## Temperature calculations

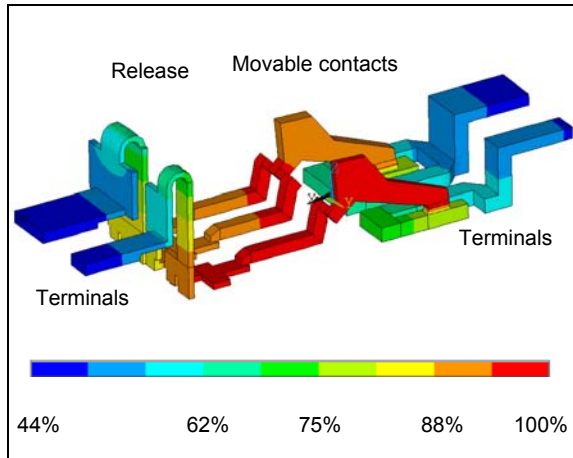
The temperature simulations are performed using a finite element model with the detailed current path representing the heat source as well as the main plastic and metal parts of housing, releases and arcing chamber.

The main mechanisms of heat dissipation are conduction along the current path to the terminals and the connected cables as well as convection and radiation at the outer surface of the housing. Due to the small size of cavities in the breaker convection can be neglected within the device.

The cables are not modelled with finite elements since that would result in excessive calculation expense. Instead they are represented by a reduced model that calculates the heat flow from the breaker to the cables taking into account the internal joule heat loss in the cable and conduction along the cable as well as convection and radiation on the cable surface as described in detail in [4].

**Fig. 2** shows a half-symmetry model of the three phases of the simulated circuit breaker with the terminals, the over-current release

and the movable contacts. The temperature distribution is shown relative to the maximum temperature occurring in the centre of the breaker.



**Fig. 2** Calculated temperature rise of the current paths

## RESULTS

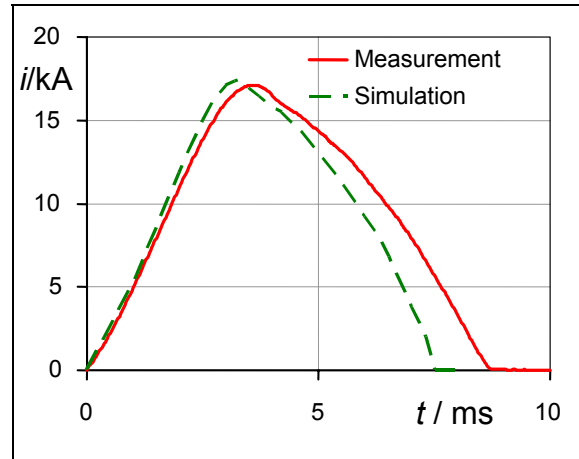
### Short-circuit calculations

The simulations were performed early in the concept stage of the development process comparing different designs to support the decision for a specific design. The measurements were done on the first prototype of the breaker.

We obtain a good agreement between calculated and measured current-time trends; especially for the current-rise phase until the let-through-current  $I_d$  is reached as can be seen in **Fig. 3** for a single-phase calculation with a prospective current of 25 kA.

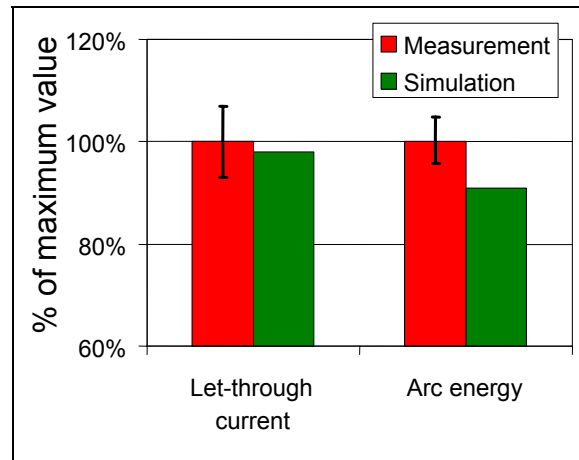
Besides the current and voltage the position of the movable contacts and the armature of the short-circuit release are calculated. This is a valuable additional information that can not be easily accessed in experiments.

The Joule integral  $Q = \int i^2 dt$  – a measure for the thermal load of the current path – and the arc energy  $W = \int u i dt$  as well as other data are evaluated from the calculated temporal values.



**Fig. 3** Measured and calculated current

**Fig. 4** represents the maximum values of the let-through current – the maximum current that exerts the highest force on the conductors – and the arc energy  $W$  for a three-phase calculation of 25 kA at 440 V. For the measurements the variation from 5 single experiments is also given. The difference of the calculated values to the experiments is less than 10%.



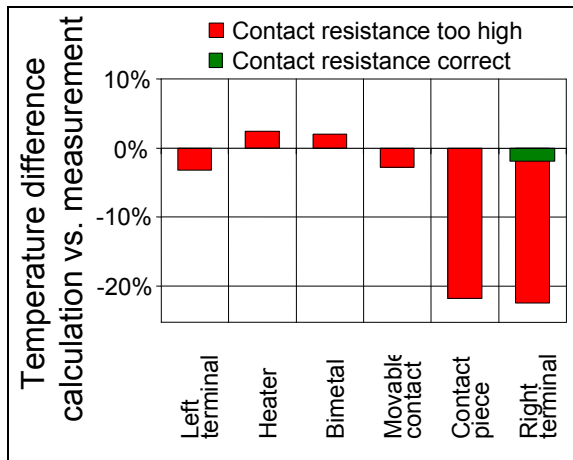
**Fig. 4** Measured and calculated let-through current and arc energy

### Temperature calculations

The difference between calculated and measured temperatures at selected positions along the left current path of the circuit breaker (phase L1) is shown in **Fig. 5**. A good agreement with a deviation of less than 5% can be seen for most positions while the temperature at the contact piece and the right terminal is underestimated by the simulation.

The reason for this difference was found to be not within the simulation model but it is

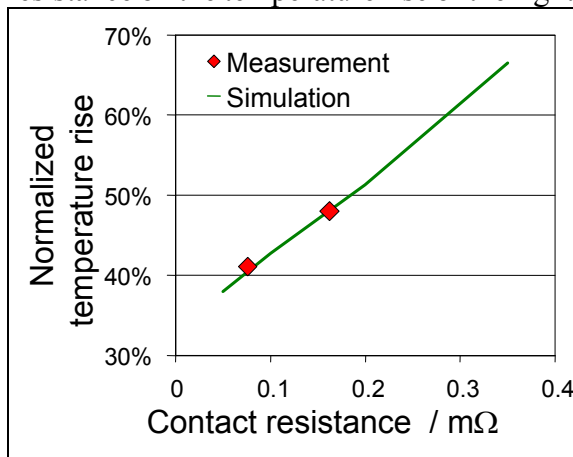
due to the fact that the tested prototype did not reach the nominal value of the contact force.



**Fig. 5** Difference of steady-state temperatures for rated current in phase L1.

This caused a higher contact resistance, increased heat loss and consequently a higher temperature. Subsequent simulations with the actual lower contact force led to a comparable (higher) temperature at the contacts as observed in the experiments. A final test with the correct contact force yielded the expected temperature at the right terminal as indicated in Fig. 5 with the green column.

**Fig. 6** shows the influence of the contact resistance on the temperature rise of the right



**Fig. 6** Influence of the contact resistance on the temperature rise of the right terminal

terminal, normalized to the maximum temperature in the breaker as shown in **Fig. 2**. It is evident, that an increase in resistance leads to a higher temperature at the terminal. Again a good agreement between measurement and simulation can be seen.

## CONCLUSION

The short-circuit behaviour of current limiting circuit breakers calculated with our network model shows a good agreement with subsequent measurements. This gives the developers a powerful tool that aids their decision early in the design stage.

Calculations of the steady-state temperature with nominal current compare well to subsequent experiments. In this specific case the calculations helped to identify a problem in the manufacturing process of the first prototype.

## REFERENCES

- [1] F. Pohl: *Simulation of short circuit interruption with dynamic opening, low voltage power circuit breakers*. Proc. 6<sup>th</sup> Internat. Conf. on Switching Arc Phenomena, Lodz, Poland, Sep. 1989.
- [2] U. Großmann, Andreas Krätzschar: *Modellierung des Schaltverhaltens strombegrenzender Leistungsschalter für transiente Netzberechnungen*. 48. IWK, Techn. Univ. Ilmenau, Germany, Sep. 2003.
- [3] Hartwig Stammberger, Heinz Pursch, Albert Zacharias, Peter Terhoeven: *Simulation of the temporal behaviour of circuit breakers and motor starters*. Proc. 20<sup>th</sup> Internat. Conference on electrical Contacts, Seattle, USA, Sep. 2004.
- [4] Hartwig Stammberger, Carsten Dehning, Michael Anheuser, Albert Zacharias: *Temperaturberechnungen für Schaltgeräte*. 16. VDE Kontaktseminar, Karlsruhe, Germany, Sep. 2001.
- [5] Frank Barcikowski, Manfred Lindmayer: *Simulations of the Heat Balance in Low-Voltage Switchgear*. Proc. 20<sup>th</sup> Internat. Conference on Electrical Contact, Stockholm, Sweden, June 2000.
- [6] SimulationX. ITI GmbH, Dresden, Germany, 2006, (<http://www.iti.de>)
- [7] ANSYS, Rev. 9.0, ANSYS Inc., Canonsburg, PA, USA, 2005, (<http://www.ansys.com>).